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United States Naval Postgraduate School

THE NPS ROCKET CORER:

A FIRST GENERATION ROCKET POWERED CORING TOOL

by

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and

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ABSTRACT:

A rocket motor powered corer has been designed and built at the Naval Postgraduate School. Limited tests of this NPS Rocket Corer, conducted in a sand-silt-clay bottom at a depth of 100 feet off Pitas Point in Ventura County, showed promising results. It has been demonstrated that available rocket motors can be used to drive coring devices in relatively shallow water. Further tests are warranted to determine the maximum depth that rocket-powered instruments may be used. It presently appears possible that rocket motors may be used as a general source of power for varied underwater applications.

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I. INTRODUCTION

Although coring tools have been in use over 100 years, there is no instrument currently in use that can reliably obtain large, undisturbed bottom samples from the deep ocean at reasonable expense. Existing equipment and methods are inadequate to meet the growing requirements.

Rosfelder and Marshall [1967] have outlined the nature of the problems associated with obtaining optimum quality cores of marine sediment. One of these problems is the selection of an efficient driving method. The best results were reported as being offered by: (1) a fast, single stroke, such as that used by gravity corers, or by implosive or explosive reaction; and (2) a slow continuous pushing, such as that obtained by hydraulic thrust, or by a controlled, hydrostatic thrust.

At the present time, rocket propulsion is being used to a limited extent as a driving method for taking deep ocean cores. Dr. N. Nasu of Tokyo University has recently developed a free fall rocket corer driven by solid rocket propellant to obtain cores one meter in length.

The NPS Rocket Corer was designed and built at the Naval Postgraduate School to investigate the feasibility of using currently available rocket motors to drive coring tools.

The use of an explosive reaction for coring was first applied by Piggot [1936], who used expanding gases from military gun propellant to drive a coring tube within a heavy cylinder similar to a gun barrel. Andresen, Sollie, and Richards [1965] designed the N.G.I. Sampler to penetrate a given distance into the bottom by gravity, after which a self contained gas generator was fired driving the sample tube about five feet further into the sediment. In principle, this device operated in much the same manner as the corer used by Piggot. A charge of rocket propellant was used as a gas generator to provide expanding gases to drive a movable piston.

The Piggot corer and N.G.I. Sampler represent examples of how propellant has been used in the past as a driving method. A disadvantage common to these corers was the need for heavy cylinders to contain the expanding gases. Such cylinders are expensive to produce, and their heavy weight aggravates handling problems during operations at sea.

The use of a conventional rocket motor to propel the coring tube eliminates the need for a heavy cylinder. The weight of the instrument can therefore be kept relatively small. The fast, single stroke produced by the thrust of the rocket motor can then be employed in developing a high performance corer.

This approach, however, presents some new problems to be overcome: the necessity of watertight enclosure to both keep the motor dry and at atmospheric pressure until ignition; and the added safety considerations associated with the handling of live ordnance. If preliminary tests show that rocket propulsion can be conveniently used to safely take long samples from the deep ocean at reasonable cost, it may be the most promising driving method for future developments.

The objective of this study was therefore to investigate the feasibility of using rocket motors to drive a core barrel capable of obtaining long samples from the deep ocean floor. To accomplish this objective a rocket powered coring tool, herein termed the NPS Rocket Corer, was designed and built. A limited operational test program was conducted. The instrument was designed as research hardware, and was not intended to be the optimum corer for immediate widespread use.

Because of the limitations in time, funds, and support devices, the design features and methods were kept as simple and inexpensive as possible.

II. PROBLEMS ASSOCIATED WITH ROCKET DRIVEN CORERS

Although our experience and knowledge in the field of rocket propulsion is vast, there has been but little research relating to the performance of rocket motors underwater. Limited tests conducted by the Naval Weapons Station, China Lake have indicated that rocket motors in sea water can produce, at least at shallow depths, thrusts comparable to that which they were designed to produce in air. The degree to which efficiency is reduced in the seawater is uncertain. The size and type of rocket motor for an underwater application cannot be selected with confidence at the present time.

One problem associated with rocket corers is that of providing the proper conditions for reliable ignition and burning of the solid propellant grain to produce thrust by the proper flow of gases through the nozzles. The conditions offering the best opportunity for this ignition and smooth burning involves keeping the motor dry and at atmospheric pressure. This can be done with a pressure cap over the nozzle end of the motor section capable of maintaining watertight integrity from the surface to the maximum operating depth of the corer. An important additional requirement is that the pressure cap lifts off when the pressure inside the motor section exceeds the water pressure. This exposes the rocket nozzles to deliver the thrust.

Sutton [1949] reported that the burning rate of propellant increases with increasing pressure, and above a certain upper limit the burning rate increases so rapidly that normal burning is no longer possible. A detonation can then occur which could shatter the motor casing. This, therefore, may be a limitation on the depth to which rocket motors can be used. The water pressure must be overcome prior to the lifting of the pressure cap. Should the water pressure exceed the limit noted by Sutton, the motor could not function beyond that depth. Sutton reported that this pressure for most propellants is above 6000 psi. Many areas of the deep ocean are within this limit. Were the need established, propellants that could resist these high pressure effects might well be developed.

There is a conspicuous safety problem associated with the development of a rocket corer. The precautions and procedures for safe storage and handling of explosive ordnance must be followed. If these are applied, rocket corers would prove as safe as the other rocket-powered devices.

The problem of preventing the motor from accidently turning about and creating a missile hazard for personnel on board the research vessel is also related to safety. A positive means must be provided to retain the rocket motor in order to prevent this. A minimum safe operating depth should also be established as an additional precaution.

A question also exists as to how the rocket motor is best ignited. There are many advantages to inclusion of a power source to provide the firing signal within the motor section itself. The possible loss of control and the possible creation of a major safety problem should a misfire or other unexpected incident occur are, however, serious disadvantages. A safer method to initiate the rocket motor is the use of a watertight firing cable with the power source located on the research vessel.

When the motor fires, it is essential that the corer be oriented vertically. One way to ensure this is to permit the corer to penetrate the bottom as a gravity corer, and then to fire the rocket motor for further penetration. It would then be difficult, however, to determine how much of the penetration was due to the gravity drop, and how much resulted from the rocket motor thrust. In the current work, a stand to hold the corer in the upright position was used to insure that all penetration was due to the rocket motor thrust.

III. THE NPS ROCKET CORER DESIGN

The NPS Rocket Corer represents a first generation research device intended for use in relatively shallow water in order to study design principles for application to later deep water rocket powered instruments. It was designed to be as simple and inexpensive as possible. It was constructed in the Machine Shop of the Naval Postgraduate School during the period of May through June of 1969. The design considerations and the design features of the various components are discussed in the following sections.

A. THE ROCKET MOTOR

The corer was designed to utilize a 2.75 Inch Rocket Motor MK 4 MOD 8. This particular motor was selected because it was available, and because its 720 pounds of thrust in air and 1.68 second burning time were considered adequate. It was modified for use in the coring tool by removing the stabilizing fins. The length of the motor without the fins is about 33.5 inches. An inert warhead was modified to act as a plug for the forward end. This plug has the effect of sealing the forward end of the motor and also increasing the length of the motor to allow the rocket nozzles to protrude beyond the motor section casing after removal of the pressure cap. This motor contains 5.9 pounds of solid rocket propellant and is equipped with an electrically activated igniter.

B. THE MOTOR SECTION

The motor section shown in Figures 1 and 2 is a cylindrical piece of stainless steel tubing that weighs about 43 pounds. The outside diameter of the tubing is 3.50 inches and the inside diameter is 2.90 inches. This particular size was selected for several reasons: it can conveniently accept the 2.75 inch diameter rocket motor; it is strong enough to withstand the forces to which it might conceivably be subjected during test operations; it is a stock item which is readily obtainable from the supplier; it is compatible with the available stock used for the fore barrel material.

A closing plug 0.5 inches in thickness was welded to the lower end of the motor section. A cylindrical mating surface 5.0 inches in length was welded to the closing plug. This mating surface was designed to slide into the core barrel. The motor section and core barrel are securely mated together by 16 bolts, 1/4 inch in diameter, which are tightened into 16 bolt holes in the mating surface. The upper core stop is welded 2 inches from the top of the motor section. Two lifting eyes 180° apart were in turn welded to the upper core stop. The top 1.25 inches of the outside surface of the motor section was carefully machined to provide a surface for the O-ring seal of the pressure cap. Two small set screw holes were drilled and tapped near the top of the motor section 180° apart to hold the rocket motor in the motor section.

C. THE PRESSURE CAP

The pressure cap shown in Figures 3 and 4 was designed to fit over the upper end of the motor section and, with the press-fit O-ring seal, to make the motor section watertight. The fact that it is essential to keep the motor dry and at atmospheric pressure until rocket ignition necessitated certain design features: the pressure seal had to function properly at maximum operating depth; and the pressure cap had to blow off after ignition when the pressure within the motor section exceeded the water pressure. It was also necessary to pass an electrical firing cable through the top of the pressure cap without sacrificing the integrity of the pressure seal. This was accomplished by utilizing a hollow bolt and gasket. The firing cable was passed through a hollow bolt and then through the top of the pressure cap. The bolt was then tightened against the gasket to provide an efficient stuffing tube.

D. THE CORE BARREL

The core barrel shown in Figures 5 and 6 is a cylindrical section of stainless steel tubing 5 feet 6 inches in length that weighs about 24 pounds. The outside diameter is 3.50 inches and the inside diameter is 3.25 inches. Mated together, the core barrel and motor section form a continuous 3.50 inch cylinder which rides smoothly between the upper and lower core stops in the sleeve cylinder of the core stand. The core barrel length has been kept short in order to reduce the handling problems during the initial test operations. Longer core barrels could be easily made for more extensive tests. This size tubing is a stock item readily available from suppliers.

Near the upper end of the core barrel are the 16 holes used for mating the core barrel to the motor section. This method of joining the two sections was selected because of its simplicity.

Twelve vent holes 1.0 inch in diameter were drilled just below the bolt holes. These are comprised of four rows of three holes each spaced 90° apart, and allow the water to escape as the sediment sample moves into the core barrel.

The lower edge of the barrel itself was sharpened to act as a crude core cutter. No core liner was used.

E. THE CORE STAND WITH SLEEVE CYLINDER

The core stand shown in Figures 7 and 8 has been designed to keep the corer in an upright position prior to ignition of the motor. It consists of four supporting legs welded to a cylindrical sleeve in which the core barrel and motor section ride between the lower and upper core stops.

A sheet metal pad has been welded to the lower end of each leg to prevent them from penetrating into the bottom.

F. THE CORE RETAINER

The core retainer is of the spring-leaf type, and is secured near the lower end of the core barrel by two small screws.

IV. OPERATION OF THE CORER

The NPS Rocket Corer is assembled for use in the following manner. The core barrel is inserted into the lower end of the sleeve cylinder. The motor section is then attached to the core barrel by means of the 16 mating bolts. STP Oil Treatment is applied to the outside surface of the core barrel and motor section between the lower and upper core stops in order to reduce friction in the sleeve cylinder. The corer is then suspended over the water.

The rocket motor is prepared for loading by securing the modified inert warhead to the forward end of the motor casing. The motor is then loaded into the motor section. The set screws are tightened to hold the motor securely in place.

The two-conductor firing cable is threaded into the stuffing tube on the top of the pressure cap. One conductor is connected to the rocket motor firing lead and the other is grounded to the motor casing. The pressure cap is then pushed into place over the top end of the motor section with the O-ring seal pressing against the surface of the motor section to create a watertight seal. The stuffing tube is also made watertight by tightening the hollow bolt against the stuffing tube gasket. A small piece of slacked nylon line is finally connected to the pressure cap and motor section to prevent the loss of the pressure cap when the motor is fired.

The corer is then lowered to the sea floor. It is held upright on the bottom in the sleeve cylinder by the core stand. In this position, the corer is ready for firing, as is shown in Figures 9 and 10.

The motor is initiated by passing electrical current through the firing cable from a suitable power source on the surface. Upon ignition, the increasing pressure inside the motor section forces off the pressure cap. The rocket nozzels are then exposed, and the motor thrust forces the core barrel into the ocean bottom. The upper stop limits core barrel penetration to 5 feet 4 inches. The corer is then retrieved and the core sample removed.

V. TEST OPERATIONS

The motor section and pressure cap were tested for watertightness to a depth of 300 feet during July, 1969. This was done in Monterey Bay using the research vessel of the Naval Postgraduate School. The results were sufficient to ensure that the pressure cap would function properly during the first corer tests.

The NPS Rocket Corer was then tested off Pitas Point in Ventura County, using the diving vessel of the Naval Civil Engineering Laboratory. On 31 July, 1969, two attempts to fire the corer failed due to a short circuit at a splice in the firing cable just above the pressure cap. This particular splice was necessary because the firing cable was not compatible with the stuffing tube of the pressure cap. Alterations were made to eliminate the need for this splice by redesigning the stuffing tube to accept the firing cable directly.

On 21 August, 1969, the corer was successfully fired in water 100 feet in depth. All components functioned properly. The core barrel was driven into the clay-sand-silt bottom to its design limit. The penetration stopped when the upper core stop struck the top of the sleeve cylinder. The core barrel was therefore driven 5 feet 4 inches into the sediment, and a core three feet in length was obtained.

Apparently only a part of the motor thrust was utilized in driving the core barrel to the design limit. A small piece of manila line had been tied to the motor section casing just below the upper core stop to absorb the shock of the upper core stop as it struck the sleeve cylinder. Upon recovery of the corer it was noted that this line was badly frayed and squeezed. The upper core stop evidently slammed into the sleeve cylinder with considerable force, suggesting that a much longer core sample could have been obtained if a longer core barrel had been employed.

The rocket motors were handled without difficulty. Standard procedures were followed and standard precautions were taken. The firing of the corer in water 100 feet in depth presented no danger to those on board the vessel. The only indication on the surface that the motor had been fired was a light tug on the firing cable followed several seconds later by bubbles coming to the surface.

VI. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The feasibility of safely using currently available rocket motors to drive coring devices has been demonstrated by this work. The NPS Rocket Corer utilizing a 2.75 inch rocket motor was successfully tested, and has obtained samples in water 100 feet in depth. The length of the core was controlled by the design limitations, which may be easily modified for future tests. Evidence indicates that only a portion of the available rocket motor thrust was used to drive the corer.

It is recommended that further tests be conducted with a longer barrel. Modifications to the stand may also prove necessary to ensure that the corer is kept in stable upright position. Such tests should establish the maximum penetration possible with this particular design. Comparisons with gravity coring done in the same area could also be made.

It has been shown that a pressure cap utilizing an O-ring seal is an effective method of keeping the motor dry and at atmospheric pressure to depths of at least 300 feet. It has also been shown that the basic pressure cap approach performs well to the test depth of 100 feet. There is probably some depth beyond which the pressure produced in the motor section would exceed the limit described by Sutton, and beyond this depth the propellant would detonate and rupture the motor section casing. Assuming the pressure cap functions properly, a corer of this design should work in many areas of the deep ocean.

Initially, further tests should be conducted to depths in which the existing pressure cap design can effectively maintain the watertight integrity. For subsequent tests to depths of several thousand feet, a new pressure cap design will probably be needed. Such a new design might incorporate an O-ring which is forced against an inclined surface as depth increases.

Future designs could include many improvements: the motor section might be of lighter construction, and larger rocket motors could be employed for greater penetration.

It might well be possible to determine the optimum motor thrust for maximum penetration of a given corer. Subsequent designs might utilize expendable motor sections with the rocket motor and pressure cap included as an integral part, so configured as to be quickly attached and later discarded after the motor was fired.

The objective of this study has been to investigate the feasibility of using rocket motors to obtain long, undisturbed core samples from the deep ocean. Tests in relatively shallow water show promising results. Future progress may be made toward a solution of the problem of obtaining long, undisturbed cores by further development of rocket driven corers. Further work in this field appears to be warranted.

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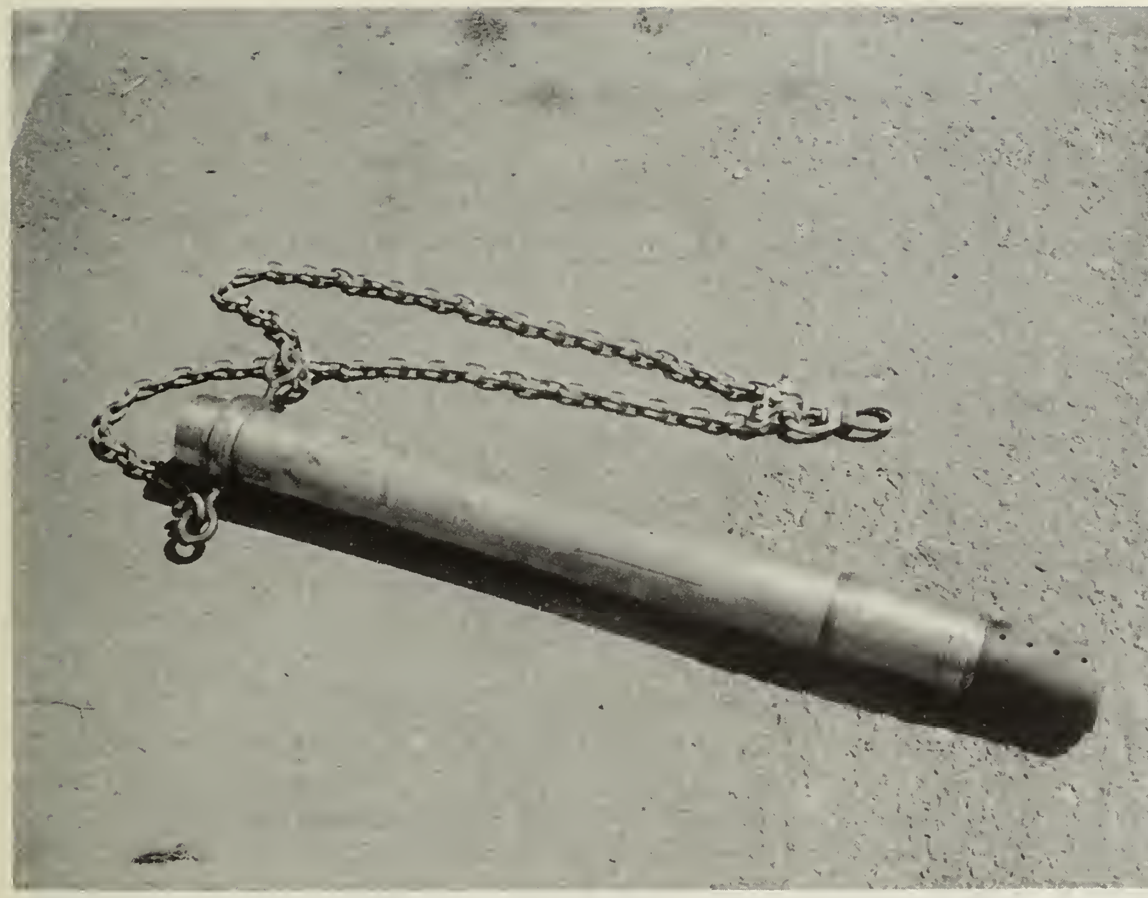


Figure 1. The Motor Section

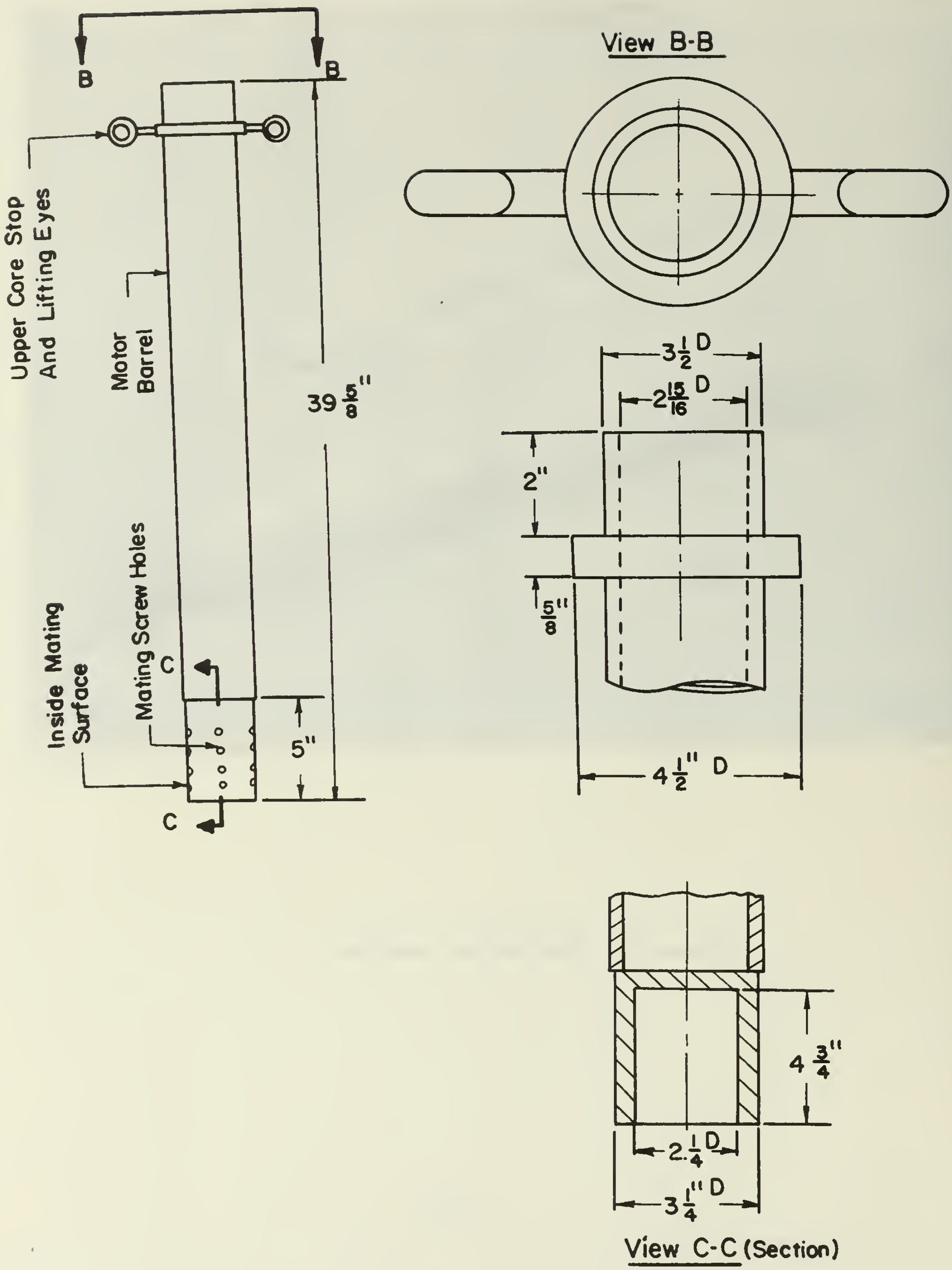
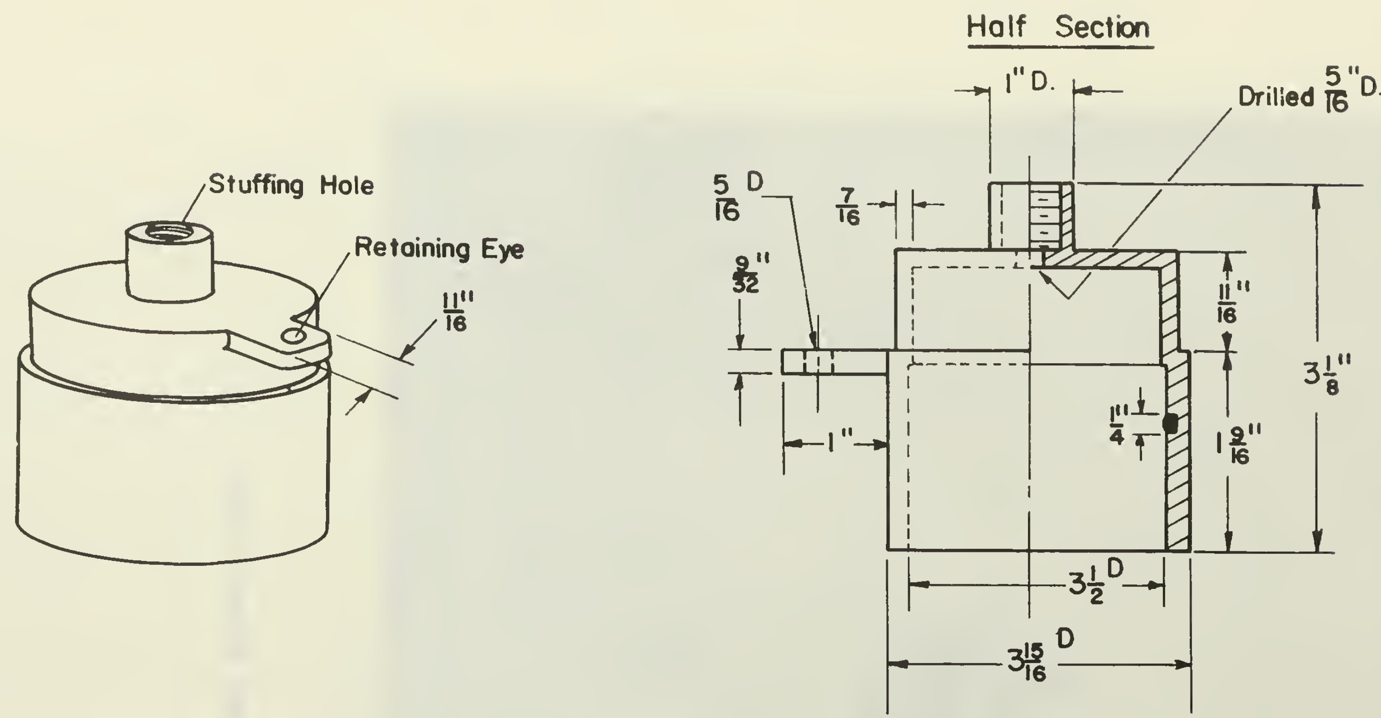


FIGURE 2

MOTOR SECTION

Figure 3. The Pressure Cap



O Ring — Set IN 1/4 x 1/8"
3/4" O.C. From Bottom

Bolt — Half Inch Thread Width, And To Have 5/16" Counter Hole Through Length.

FIGURE 4
PRESSURE CAP

Figure 5. The Core Barrel

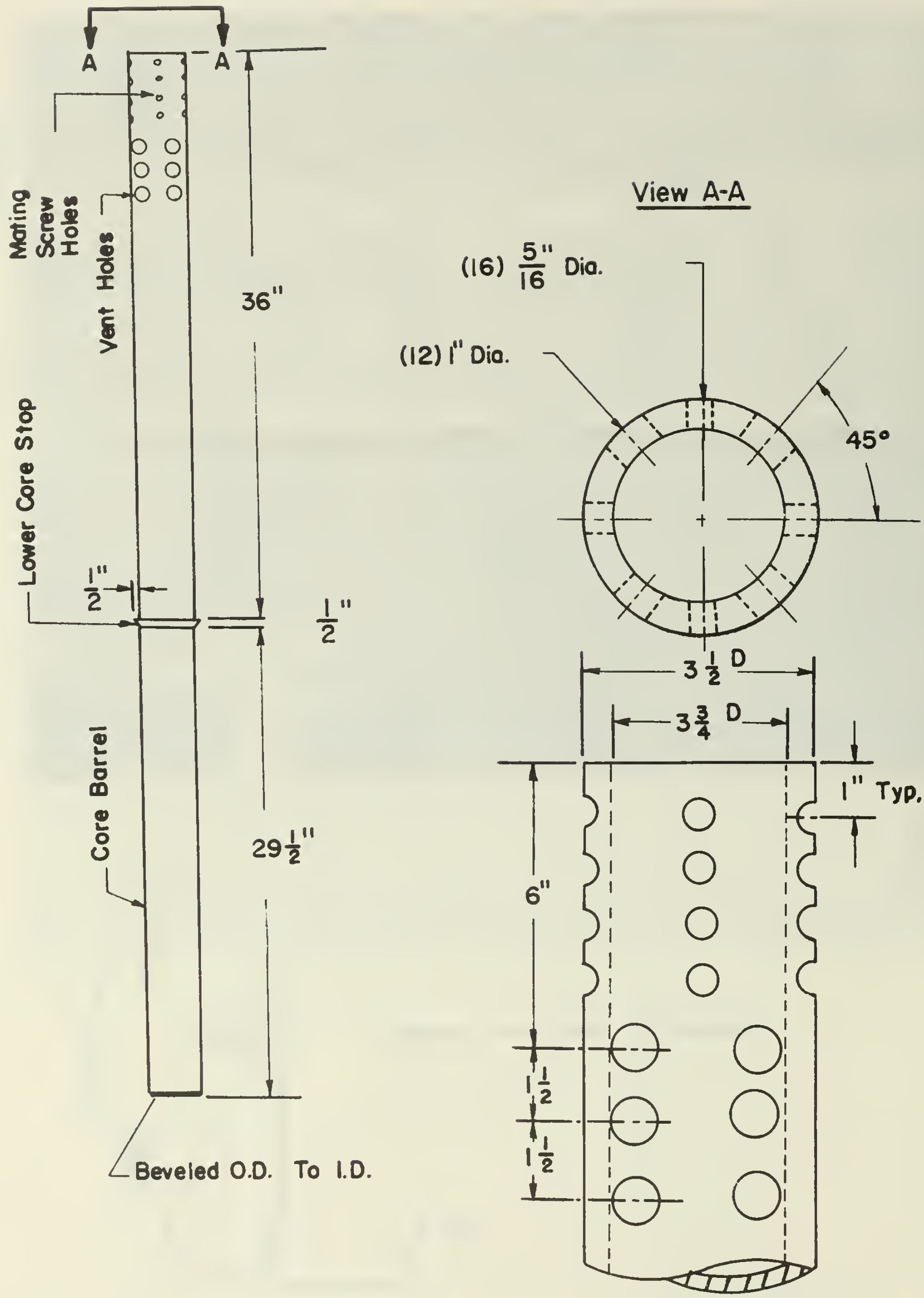


FIGURE 6

CORE BARREL

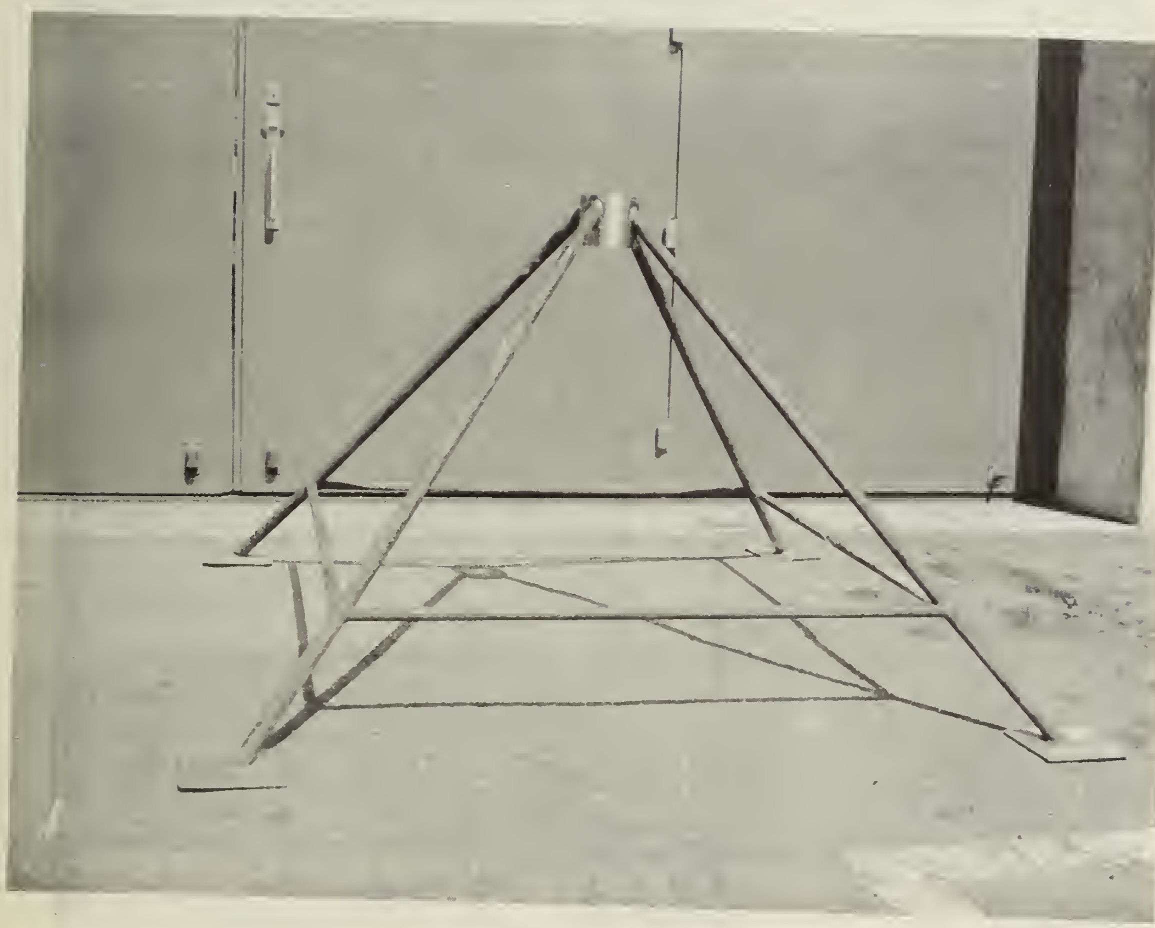


Figure 7. The Core Stand with Sleeve Cylinder

NOTES.

(1) Stand = $33\frac{7}{8}''$ High.

(2) Legs = 1'' Dia.

(3) Bracing = $\frac{7}{8}''$ Dia.

(4) Leg Plates = 6'' Squares

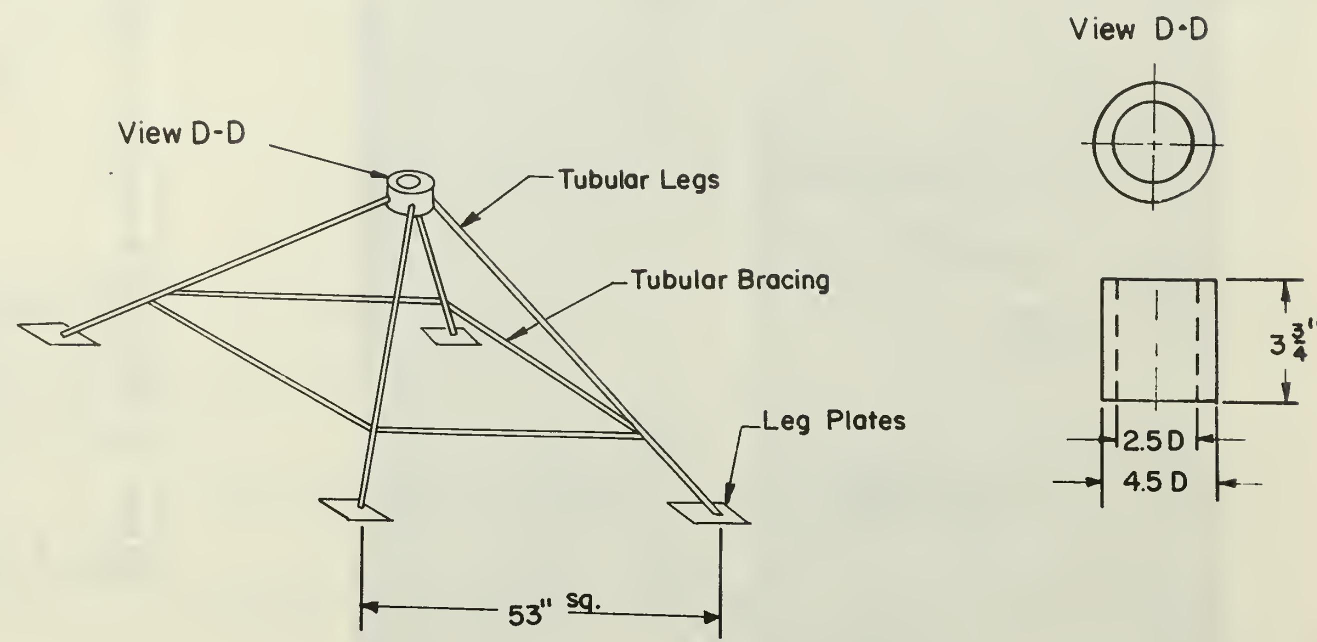


FIGURE 8

STAND WITH SLEEVE CYLINDER

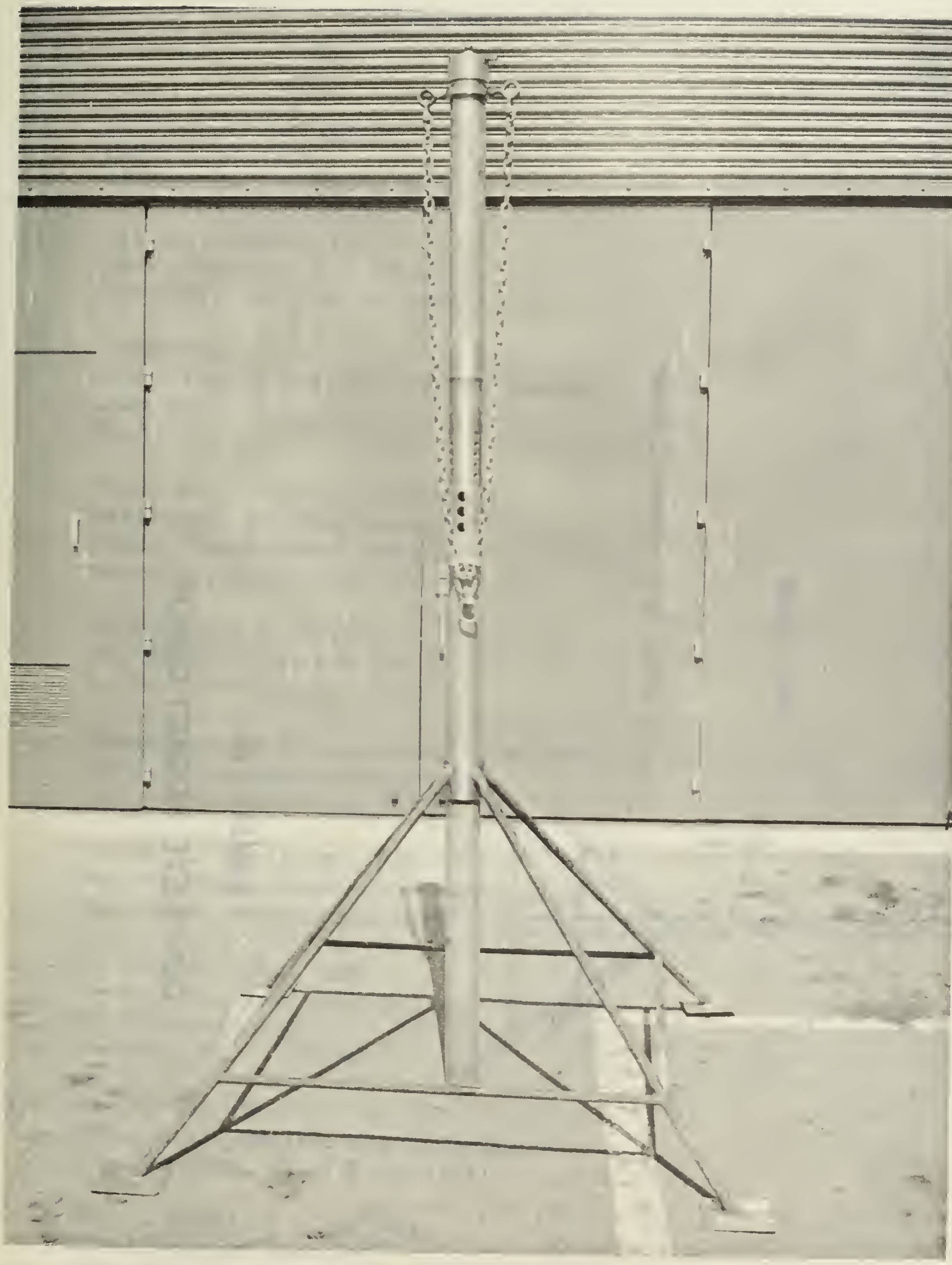


Figure 9. The NPS Rocket Corer

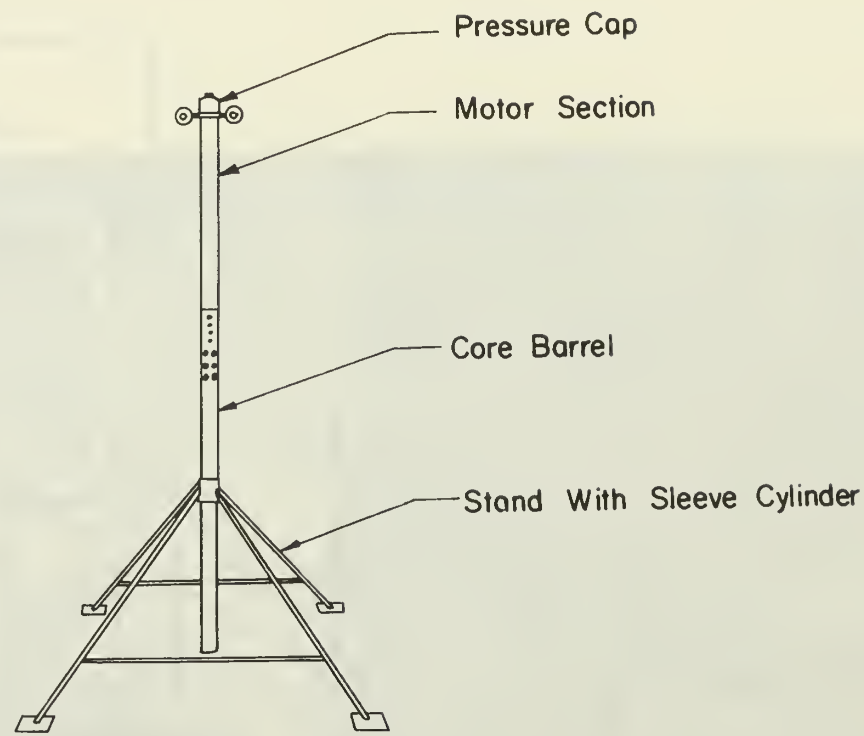


FIGURE 10

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13. ABSTRACT

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Coring Tools						
Sediment Sampling						
Sediment Corer						
Rocket Corer						
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